



Report to the Chairman, Subcommittee
on Energy and Power, Committee on
Energy and Commerce, House of
Representatives

December 1989

NAVAL PETROLEUM RESERVE NO. 1

Work Still Needed to Improve Accuracy of Reserve Estimates



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Resources, Community, and
Economic Development Division

B-237661

December 13, 1989

The Honorable Philip R. Sharp
Chairman, Subcommittee on Energy
and Power
Committee on Energy and Commerce
House of Representatives

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Dear Mr. Chairman:

In response to your request and subsequent discussions with your office, we reviewed and analyzed the new reserve data presented in a July 1988 reserve study for Naval Petroleum Reserve No. 1, located in Kern County, California. We also examined other data used in that study, including the results of an exploratory test well completed at the field.

As arranged with your office, unless you publicly announce its contents earlier, we will make no further distribution of this report until 30 days from the date of this letter. At that time, we will send copies to the Director, Office of Management and Budget; the Secretaries of Energy and Defense; and other interested parties.

This work was performed under the direction of Keith O. Fultz, Director, Energy Issues (202) 275-1441. Other major contributors are listed in appendix II.

Sincerely yours,



J. Dexter Peach
Assistant Comptroller General

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Executive Summary

Purpose

For several years, the administration has proposed selling the government's ownership interest in the Naval Petroleum Reserves (NPR), on the basis of a claim that it would help reduce the federal budget deficit. The administration's latest proposal, made in February 1989, called for the sale of the reserves in fiscal year 1990. The Department of Energy (DOE) estimates that if the NPRs are sold in 1990, proceeds from a sale could be about \$3.4 billion. The Naval Petroleum Reserve at Elk Hills, California (NPR-1) is the largest of the reserves and is jointly owned with Chevron, U.S.A. Inc. One of the key problems that DOE faces in analyzing the government's ownership interest in NPR-1 is that reserve data are not up-to-date and accurate. In February 1988, DOE's Assistant Secretary for Fossil Energy testified before the House Committee on Budget that a reserve report was being prepared for NPR-1 to produce firm reserve estimates so that potential bidders would know how much oil is in the ground. DOE hired a firm to prepare a comprehensive reserve report for NPR-1, which was delivered in July 1988.

Citing the need for an independent assessment of DOE's efforts to sell NPR-1, the Chairman, Subcommittee on Energy and Power, House Committee on Energy and Commerce, asked GAO to review and analyze the accuracy of the new reserve data presented in the July 1988 reserve study.

Background

NPR-1 is a geologically complicated oil field. Although it has four known geologic zones in which petroleum has been trapped, production primarily occurs in the Stevens and Shallow Oil Zones. The government and Chevron own the field (about 78 percent and 22 percent, respectively) and have been operating it since 1944 through a unit agreement that specifies how production and expenses are shared.

The 1988 reserve study was expected to provide new reserve estimates for use in developing and producing the reserve, and assessing the effect of historical development and production on recoverable reserves. The study consisted of three phases that were performed over a 6-month time frame at a cost of about \$1.9 million. An optional fourth phase was included in the contract—the first part (phase IV a) authorizes additional geology and engineering studies if data developed in the first three phases are not adequate, and the second part (phase IV b) authorizes a reevaluation of the government's share in NPR-1.

Results in Brief

DOE's revised reserve estimates for NPR-1 are still not accurate and up-to-date. The 6-month contract time frame allowed the contractor to organize a large amount of existing NPR-1 data into a single reserve report. However, the contractor did not have sufficient time to prepare new technical analyses needed to address uncertainties in the data. These uncertainties reduced the reliability of the reserve estimates. To improve the accuracy of these estimates, the contractor recommended additional geologic and engineering studies to clear up the uncertainties in the data used.

DOE has recognized that additional work is needed. DOE told GAO that the work it is now carrying out under phase IV a of the contract, along with other work at NPR-1, will address most of the uncertainties. In addition, DOE is studying two other factors—deep well testing and enhanced oil recovery methods—that could substantially increase the estimated proved reserves at NPR-1. Until DOE completes these studies, it will not be possible to accurately assess the reserve estimates, and consequently, the value of NPR-1.

Principal Findings

Reserve Estimates Not Substantially Improved

One of the contractor's major accomplishments was that it organized a large amount of NPR-1 data obtained during the collection process into a single reserve report. The report also assesses the impact of past development practices on the field's reserves and for the first time places NPR-1 reserves into categories (proved, probable, and possible) that reflect the degree of risk associated with their recovery as defined by the Society of Petroleum Engineers. However, DOE's revised reserve estimates are not accurate and up-to-date because a 6-month contract time frame was not long enough to permit the contractor to do technical analyses of the field and support individual field studies on a well-by-well basis. To meet the contract date, the contractor used the best available data from other NPR-1 contract studies that were reviewed and spot-checked for accuracy.

The contractor estimated that, after July 1, 1988, gross oil and gas reserves of about 831.5 million barrels of oil and 1.65 trillion cubic feet of gas remain to be recovered at NPR-1. The contractor estimated that there was reasonable certainty of recovering about 335.6 million barrels of oil and about 1.4 trillion cubic feet of gas, or about 40 percent of the

oil and about 85 percent of the gas (proved reserves). However, the contractor placed the remaining 495.9 million barrels of oil and 257.1 billion cubic feet of gas into reserve categories which reflect a greater degree of risk. The risk is related to confidence in the existence and recovery of the reserves, and the recovery method to be used.

Factors Affecting the Estimate

GAO believes that two key factors affected the accuracy of the reserve estimates.

- Geologic maps and descriptions were not precise enough to calculate the amount of original oil and gas in-place accurately.
- The movement of fluids between producing pools and strata within the 31S Structure in the Stevens Oil Zone, although acknowledged by the contractor, was not fully developed and reflected in the revised estimates of original oil and gas in-place.

Because of these two factors, two engineering methods used by the contractor produced widely different estimates of original oil and gas in-place for many of the pools in the Stevens Oil Zone. A general rule is that higher confidence is placed on the oil and gas in-place estimates if the values produced by each method are relatively close.

Additional Studies Needed

The contractor believes that many of the uncertainties that caused him to apply risk factors to the revised reserve estimates can be reduced with better and more accurate data. Twenty-six of the 33 studies recommended by the contractor would review areas of the field associated with about 516.9 million barrels of oil (62 percent) and 326.1 billion cubic feet of gas (20 percent) included in his recoverable reserve estimates. About 21 million barrels of oil and 69 billion cubic feet of gas of this amount are in the proved reserve category. The remaining 495.9 million barrels of oil and 257.1 billion cubic feet of gas are currently considered less certain and are in reserve categories that have been assigned risk factors. An additional 7 studies pertain to areas of the field associated with another 24.3 million barrels of oil and 17 billion cubic feet of gas that were not even included in the reserve estimates because they were considered speculative.

In October 1988, DOE started phase IV a of the contract at an estimated cost of about \$1.09 million. According to DOE, this 1-year contract will address parts of 11 recommended studies and is intended to improve

geologic descriptions and address fluid migration problems in the Shallow Oil and Stevens Oil Zones. Overall, DOE believes that the phase IV a work and other work that is either completed, planned, or underway will address 30 of the 33 recommended studies. Until DOE completes the phase IV a and other planned and ongoing work at NPR-1, it will not be possible to accurately assess how the work will affect the reserve estimates for the field.

Finally, DOE has not decided whether to authorize the contractor to carry out the part of the contract relating to reevaluating ownership shares in NPR-1 that is planned under phase IV b.

Additional Issues That Could Affect Reserve Estimates

In addition to the studies recommended by the 1988 reserve study, DOE is carrying out other tests that could affect the accuracy of NPR-1's reserve estimates. These tests pertain to (1) the extent of potential oil and gas resources in the deep zones below the existing unit and (2) the use of enhanced oil recovery techniques such as steam flooding in the Shallow Oil Zone. The July 1988 report and past work at NPR-1 have not provided the data needed to fully address these issues.

Recommendations

GAO is not making recommendations in this report.

Agency Comments

GAO discussed this report with DOE officials. They generally agreed with the facts presented, and suggested several changes that were incorporated where appropriate. However, as requested, GAO did not obtain official agency comments on this report.

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Abbreviations

bcf	billion cubic feet
Btu	British thermal unit
DOD	Department of Defense
DOE	Department of Energy
EOR	Enhanced Oil Recovery
GAO	General Accounting Office
MBB	Main Body B
MMSTB	million stock tank barrels
MER	Maximum Efficient Rate
NPR	Naval Petroleum Reserve
NPR-1	Naval Petroleum Reserve No. 1
NPR-2	Naval Petroleum Reserve No. 2
NPR-3	Naval Petroleum Reserve No. 3
SPR	Strategic Petroleum Reserve

Introduction

The Naval Petroleum Reserve at Elk Hills, California (NPR-1), is the eighth largest domestic producing oil field. As of January 1988, Department of Energy (DOE) information showed that the field could ultimately yield reserves estimated at about 1.5 billion barrels of crude oil. The field is jointly owned by the federal government (about 78 percent) and Chevron U.S.A. Inc. (about 22 percent), and the two owners participate in the operation of NPR-1 through a unit agreement that specifies how production and expenses are shared. The unit agreement was signed by the federal government and the Standard Oil Company of California (Chevron's predecessor) on June 19, 1944.

In 1986, 1987, 1988, and again in 1989, the administration proposed to sell the federal government's ownership interests in NPR-1 and Naval Petroleum Reserve No. 3 (NPR-3), located in Natrona County, Wyoming. (Naval Petroleum Reserve No. 2, also located in Kern County, California, was not included in the sale proposal because it is leased.) In August 1988, we issued a report that examined DOE's June 30, 1987, report to the Congress on the divestiture of NPR-1, the larger of the two reserves.¹ We concluded that one of the key problems the government faced in analyzing the sale of the government's ownership interest in NPR-1 is that oil and gas reserve data are not up-to-date and accurate. One of our recommendations recognized the need for assessing a value to the government of retaining and producing NPR-1 using revised estimates from a comprehensive reserve study.

In February 1988, DOE's Assistant Secretary for Fossil Energy testified before the House Committee on Budget on the NPR sale. In response to questions by the committee on when DOE would have reserve estimates of oil in the ground, the Assistant Secretary stated that DOE had just retained a contractor to furnish complete and firm estimates of the reserves. That study (referred to herein as "the 1988 reserve study") was completed in July 1988 and cost about \$1.9 million.

In his letter of March 30, 1988, the Chairman, Subcommittee on Energy and Power, House Committee on Energy and Commerce, asked us to assist the Congress in monitoring several technical aspects related to NPR-1 operations, particularly the factors affecting the timing of the sale. As agreed with his office, this report analyzes the accuracy of the

¹ Naval Petroleum Reserve No. 1: Examination of DOE's Report on Divestiture (GAO/RCED-88-151, Aug. 25, 1988). NPR-3 was not included in our examination because of its small remaining reserve estimate.

new reserve data in the 1988 reserve study and other data used in that study.

NPR-1's History as a Government-Owned Oil Field

NPR-1 was established by executive order in 1912 to ensure a source of petroleum for the Navy. Except for several years of leased production in the 1920s, production for national defense purposes in World War II, and a period of production to protect against the drainage of oil to other oil company wells outside NPR-1 in the 1950s, NPR-1 was shut-in or produced at the minimum level necessary to prevent damage to the field, until 1976, in order to preserve the oil for future use. Following the Arab oil embargo in 1973-74, the Naval Petroleum Reserves Production Act of 1976 (P.L. 94-258, Apr. 5, 1976) was enacted to authorize NPR crude oil production at the maximum efficient rate (MER) for 6 years.² The act authorized the President to extend production further in intervals of up to 3 years after certifying that continued production was in the national interest. In accordance with the act, the President informed the Congress in 1981, 1984, and again in 1987 of his certification that it was in the national interest to continue production of the NPR at the maximum efficient rate for another 3 years. The current 3-year period ends on April 5, 1991.

Changing Role of NPR-1

From its original role as an emergency supply of oil, NPR-1 has evolved over time to an income-generating federal business asset. From 1976 through August 1980, the government's share of crude oil production was sold exclusively on the open market. Since then, some of the reserve's oil production has been exchanged by the government for oil delivered to the Strategic Petroleum Reserve (SPR), and the rest has been sold on the open market.

As of September 30, 1988, DOE's records show that over 895 million barrels of oil have been produced from NPR-1. NPR-1's average production for fiscal year 1988 was about 107,000 barrels of oil per day, 359 million cubic feet of gas per day, and 647 million gallons of liquid gas products per day. The government's share of petroleum³ production to date has generated over \$12.5 billion in revenues, almost all since it was opened

²MER is the maximum sustainable daily oil and gas rate which will permit economic development and depletion of the reservoir without detriment to ultimate recovery. Ultimate recovery is the total expected amount of crude oil and/or gas which can be produced from a field.

³In this report, the term "petroleum" includes crude oil, natural gas, and natural gas liquids.

up for full production in 1976. Total revenues from the sale of the petroleum and related products from the NPRs in fiscal year 1988 were about \$642 million.

Proposals to Sell NPR-1

In fiscal years 1986 and 1987, the administration proposed to sell NPR-1 and NPR-3 to help reduce the federal deficit, among other reasons. A third proposal in fiscal year 1988 also noted another purpose of the proposed sale was to eliminate nonessential federal activities by turning them over to the private sector. The administration's latest sale proposal was made in February 1989 and restates the administration's 1988 policy. In order to finance the purchase of oil for the SPR, the proposal calls for the sale of NPR-1 and NPR-3 in 1990 for \$1 billion, plus 50,000 barrels of oil per day for 6 years for the SPR and a new Defense Petroleum Inventory.⁴ In May 1989, DOE advised the Congress that the total cash proceeds could amount to \$3.4 billion. The Defense Petroleum Inventory would establish a 10-million-barrel inventory of oil for the Department of Defense's (DOD) use in conjunction with the SPR. The administration stated that such action would accelerate the filling of the SPR at lower cost, increase energy security, and strengthen national security.

NPR Marketing Plan Cites Need for Reserve Study

As part of its efforts to sell NPR-1 and NPR-3 in 1987, DOE developed data to determine the value of the NPRs' assets from the private sector's viewpoint and to develop a marketing plan to maximize the sales proceeds. This work was started on February 26, 1987, when a contract was let to have Shearson Lehman Brothers, Inc. (now Shearson Lehman Hutton, Inc.), develop a marketing plan that would maximize the value the government would receive in a sales transaction. Shearson delivered a marketing plan to DOE on May 10, 1987, and DOE submitted its report, entitled Divestiture of the Naval Petroleum Reserves, to the Congress on June 30, 1987.

Because of the perceived uncertainty on the part of bidders about a realistic basis for bid prices, Shearson recommended that in preparing for the sale, DOE contract for a comprehensive reserve report by a nationally recognized, independent petroleum engineering consultant. Shearson estimated that it would initially take 4 to 6 months to prepare a report. According to Shearson, various uncertainties existed as to the amount of

⁴Congressional Budget Request for fiscal year 1990 and a document titled Building a Better America, February 9, 1989.

oil and gas present, how much could be produced, and at what rate of production over the life of the field.

These uncertainties are due, in part, to NPR-1's complex geology. NPR-1 has four known, commercially productive geologic zones in which petroleum has been trapped. These zones have been designated by DOE as the Dry Gas, Shallow Oil, Stevens, and Carneros Zones. One other zone—the Tulare—is currently unproductive. Within the four productive zones, the unit has a number of pools of varying size and complexity.

Crude oil production comes primarily from two geologic zones—the Stevens and Shallow Oil Zones. The crude oil from the Stevens Zone is light, high-quality oil, while oil from the Shallow Oil Zone is somewhat heavier. Although the overall zone structures are generally known, the geology within the zones is complex and not yet completely understood.⁵

According to Shearson officials, a current, independent estimate of future production was needed both for ongoing management of NPR-1 and for informing prospective purchasers, and should be in a form and of a quality acceptable to the private sector.

DOE Hires Firm to Estimate NPR-1's Oil and Gas Reserves

On January 22, 1988, DOE contracted with the firm of Jerry R. Bergeson & Associates, Inc. (petroleum consultants), to estimate NPR-1's reserves. The firm was to use standards developed by the Society of Petroleum Engineers to estimate the amount of oil and gas that is ultimately recoverable. The first three mandatory phases of the contract were performed over a 6-month contract period.

Final reports for the first three mandatory phases were delivered to DOE by July 1988 at a cost of about \$1.9 million. The first report presents data on pool/zone descriptions. The second report establishes revised estimates of the original oil and gas in-place for each of the pools/zones; estimates of the remaining proved developed, proved undeveloped,

⁵Commercial deposits of crude oil and natural gas are contained in the pore spaces of various types of rock. An underground geologic feature containing the oil and gas is called a structure. A single such deposit of petroleum is a pool. The term "pool" as used at NPR-1 refers to one or more oil-bearing strata (layers) that have been grouped together because of their geologic linkage for purposes of development and production. A zone is an informal name used at NPR-1 for one or more pools with similar geologic age and/or oil quality characteristics.

probable, and possible reserves; and an assessment of the effects of historical development, and production operations and practices on recoverable reserves.⁶ These revised reserve estimates serve as the basis of the third report that presents an economic development and production plan for the field.

The contract has a two-part optional fourth phase. The first part (part IV a) is a contingency provision that allows DOE to develop more detailed estimates on individual pools if DOE determines that additional geologic and engineering analyses are needed. Work under phase IV a was started on October 26, 1988, at an estimated cost of about \$1.09 million. Jerry R. Bergeson & Associates, Inc., was also selected as the contractor. The second part of phase four (part IV b) would authorize studies to be used in reevaluating ownership shares in NPR-1. These shares are reevaluated periodically when new information becomes available. As of October 1989, DOE had not committed itself to undertaking the phase IV b work with the contractor. However, some technical studies of a portion of the ownership shares for the Shallow Oil Zone have already been undertaken with another contractor, and renegotiations for that zone are presently underway. (See discussion below and in ch. 3.)

Other Contract Studies and Exploration at NPR-1

Since 1942, numerous pool/zone reports and technical papers have been prepared at NPR-1 by the Navy, DOE, and its contractors. These reports and papers are used by the government as one source of information for the day-to-day operation of the field, future redetermination of its equity position with Chevron, and exploratory drilling in new areas.

Field Management Studies

These are the most common and often used studies at NPR-1. Prominent among this type are studies pertaining to major pools and zones such as the recently completed 31S Structure, 26R Pool, and the Shallow Oil Zone (western sections) studies. Summaries of these studies are presented in appendix I. Engineering studies are also done to determine the maximum efficient production rates for selected pools.

Equity Studies

The ownership split of petroleum at NPR-1 between Chevron and DOE is not necessarily fixed at the current percentages and is subject to change.

⁶These are reserve categories that are in accordance with the definitions published by the Society of Petroleum Engineers in the May 1987 issue of the *Journal of Petroleum Technology*. These categories are defined in chapter 2.

For instance, these changes can occur when new geologic information becomes available on a productive zone, or if a pool's oil and gas are totally depleted. When engineering and geologic data about the nature and extent of individual producing sand and shale formations at the field are obtained, there may be a need to determine changes in DOE's and Chevron's ownership interests. The owners' original 1942 equity positions contained in the unit agreement for the Stevens and Shallow Oil Zones were redetermined in 1947 and 1949, respectively. A second redetermination for each zone occurred in 1957. The last redetermination was done for the Stevens Zone only on an interim basis in 1980. An equity renegotiation of the Shallow Oil Zone, presently underway, may result in a change in equity shares for that zone.

Exploratory Studies

Exploratory wells have been drilled by DOE contractors at NPR-1 since 1976. The latest one, Well 934-29R, was drilled in 1987 and was the deepest drilled in California to date. In March 1988, the prime contractor issued a report that assesses the sands penetrated by the well. As a result of the increased geologic understanding of the deeper zones derived by the drilling of this well, new drilling prospects have been identified at the field.

Objectives, Scope, and Methodology

In light of our recommendation to DOE to develop accurate and up-to-date reserve estimates at NPR-1 and the administration's proposal to sell the field, the Chairman, Subcommittee on Energy and Power, House Committee on Energy and Commerce, asked us to review and analyze the accuracy of the new reserve data collected in a July 1988 reserve study and other data used in this study. This includes information on an exploratory test well at NPR-1.

To determine the accuracy of the July 1988 reserve study, we examined and analyzed data from the study to identify (1) what new information it contained on NPR-1's reserves, (2) the study's limitations in view of past data and operating problems at the field, (3) the additional work that is being recommended to improve the accuracy of the reserve estimates and possibly increase proven recoverable reserves, and (4) the usefulness of the reserve study in view of DOE's proposed sale of the field. We did not independently recalculate reserves for the field, nor did we determine the estimated market value of the field on the basis of this work. We also did not compare the 1988 reserve study with similar reserve studies of other fields proposed for sale.

We reviewed and analyzed the geologic and engineering work performed by the contractor and its subcontractors. Sigma Consultants, a DOE subcontractor, was hired by Bergeson to conduct geologic analyses and prepare final pool descriptions for the study. To determine the extent of Sigma's changes and modifications to existing field data, we compared selected Sigma pool descriptions and maps with geologic data and other studies obtained from DOE. This was done for the N, A, and B shales; 2B, 24Z-13R, and 29R pools of the Stevens Zone, and the Shallow Oil Zone. For the Stevens Zone 26R Pool, one of the major producing units in the field, we analyzed well log data, pool maps, and Sigma's oil and gas in-place calculations. Finally, Sigma's pool descriptions were traced to the contractor's final report, and we determined how they were used to calculate original oil and gas in-place for the Stevens Oil and Shallow Oil Zones.

We reviewed the contractor's recoverable reserve calculations and the methodology used to prepare them and compared them with various standards of the Society of Petroleum Engineers. We examined the impact of fluid (oil, gas, and water) movements between pools on the contractor's calculations by comparing oil and gas in-place estimates obtained in various engineering calculations. In addition, we examined work conducted by Surtek, another DOE subcontractor hired to evaluate enhanced recovery for various pools at the field.

We analyzed the additional geologic and engineering studies recommended by tracing back the contractor's estimate of the amount of oil and gas that is subject to revision if the additional work is conducted to its original analyses. We also compared the contractor's recommendations with those made in previous NPR-1 contract studies. We did not verify all of the additional analyses that are needed to provide DOE with accurate and up-to-date data.

Other recently completed contract studies of significant oil and gas areas of the field were used to provide geologic and engineering data for the 1988 reserve report. Regarding those studies concerning the 31S Structure, the 26R Pool, and selected areas of the Shallow Oil Zone, we reviewed reports and maps from these studies. We compared those studies with previous contract reports for the same areas of the field and interviewed DOE and Chevron on their acceptance and willingness to use the studies in day-to-day field operations at the field.

In analyzing information on the exploratory test well, we reviewed and compared DOE's March 1988 report, which summarizes geologic and

engineering data taken from the well, with data from other exploratory test wells at NPR-1. We also examined in detail the well logs from the well.

We conducted our review at DOE headquarters in Washington, D.C., and the NPR-1 site in California, from May 1988 through August 1989. We interviewed officials and technical staff from DOE, the unit operator, and Chevron at the NPR-1 site in California. Contractor officials, as well as DOE headquarters officials from the Office of Fossil Energy and the Office of Procurement, were interviewed in Washington D.C. We also interviewed other petroleum industry officials about reserve studies and technical data used for selling producing oil field holdings, and reviewed government lease sale procedures for oil and gas properties. In addition to these interviews, we reviewed pertinent agency files and documents, including various contract files.

We were assisted in our work by Michael T. Prendergast, a petroleum engineer on detail to us from the Minerals Management Service, Department of the Interior and by a staff geologist. We performed our work in accordance with generally accepted government auditing standards.

Reserve Report Estimates NPR-1's Oil and Gas Reserves

One of the contractor's major accomplishments was that it organized a large amount of NPR-1 data obtained during the collection process into a single reserve report. The report also assesses the impact of past development practices on the field's reserves and places NPR-1 reserves into categories as defined by the Society of Petroleum Engineers for the first time.

The reserve study developed estimates of original oil and gas in-place at NPR-1, the amount of oil and gas that remains to be recovered after July 1, 1988, and an economic development and production plan for recovering them. The study estimated gross reserves of about 831.5 million barrels of oil and 1,659.6 billion cubic feet of gas in NPR-1 after July 1, 1988.¹ The economic development and production plan prepared in the study estimated expected reserves of about 445 million barrels of oil and 1,575 billion cubic feet of gas. However, as discussed in chapter 3, there is considerable uncertainty regarding the estimates' accuracy.

Original Oil and Gas In-Place Estimates

The 1988 reserve study estimated original oil and gas in-place on an individual pool basis for the six zones at NPR-1. These oil and gas in-place figures reflect the amounts of oil and gas that were at the field before production started. This calculation is critical in the reserve study since making the in-place estimates is the first step in estimating the remaining recoverable amounts of oil and gas at the field. The oil and gas in-place estimates are based on geologic and engineering analysis, and a review of historical pool performance. In cases where the analytical techniques used did not produce consistent results, the study selected the value which appeared most reasonable and most consistent with available data.

As shown in table 2.1, the study estimated that there were about 4.4 billion barrels of oil and 3.03 trillion cubic feet of gas originally in-place at NPR-1. Most of this oil and gas was in two NPR-1 producing zones. The Stevens Oil Zone had about 2.8 billion barrels of oil (about 64 percent) and about 2.43 trillion cubic feet of gas (about 80 percent). The Shallow Oil Zone had about 1.57 billion barrels of oil (about 36 percent) and about 207.7 billion cubic feet of gas (about 7 percent).

¹The contractor initially referred to oil and gas reserves as gross reserves. These reserves, after having been risked and for which economic potential had been determined, were referred to as "expected reserves."

Table 2.1: Estimated Original Oil and Gas In-Place for NPR-1 as Revised in DOE's July 1988 Reserve Study

Oil zone	Original oil and gas in-place			
	Oil	MMSTB ^a	Percent	Gas
				bcf ^b
			Percent	
Shallow Oil Zone	1,566.6	36		207.7
Stevens Oil Zone	2,810.1	64		2,429.1
Other zones ^c	6.7			391.5
Total	4,383.4			3,028.3

^aMillion stock tank barrels. Stock tank barrels represent oil that is measured at standard surface conditions.

^bBillion cubic feet.

^cTulare, Dry Gas, and Carneros Zones; and the Asphalt Field.

Remaining Recoverable Reserves

After original oil and gas in-place were estimated by zones, the contractor used various methods of production performance analyses, when they were available, to estimate remaining recoverable reserves after July 1, 1988. The reserve study assigned the recoverable reserves to five categories based on the degree of certainty associated with their recovery. The five categories used are as follows:

- Proved developed reserves are reserves that can be estimated with reasonable certainty to be recoverable under current economic conditions. Current economic conditions include prices and costs prevailing at the time of the estimate. These reserves are expected to be recovered from existing wells.
- Proved undeveloped reserves are reserves that are expected to be recovered (1) from new wells on undrilled acreage, (2) from deepening existing wells to a different pool, or (3) where a relatively large expenditure is required to (a) recomplete an existing well or (b) install production or transportation facilities for primary or improved recovery projects.
- Probable reserves are reserves that are less certain than proved reserves and can be estimated with a degree of certainty sufficient to indicate that they are more likely to be recovered than not.
- Possible reserves are reserves that are less certain than probable reserves and can be estimated with a low degree of certainty, insufficient to indicate whether they are more likely to be recovered than not.
- Possible enhanced oil recovery (EOR) reserves are reserves associated with new drilling and EOR projects, such as steamfloods, where such

projects are assessed to have a high degree of uncertainty due to either a lack of data or conflicting data on which to base the reserve estimate.²

As shown in table 2.2 the study estimated gross reserves of about 831.5 million barrels of oil and 1,659.9 billion cubic feet of gas remain to be recovered after July 1, 1988. This represents about 49 percent of the 1,692.7 million barrels of oil reserves and about 73 percent of the 2,286 billion cubic feet of gas which the study estimated as being ultimately recoverable over the life of the field.

Table 2.2: Estimated Remaining Gross Oil (Crude and Condensate) and Natural Gas Reserves at NPR-1 After July 1, 1988

Reserve category	Gross reserves after July 1, 1988	
	Crude and condensate (MMSTB)	Produced gas (bcf)
Proved developed	335.6	1,402.8 ^a
Proved undeveloped	25.4	70.7
Probable	44.8	122.9
Possible (excludes EOR)	67.2	27.6
Possible EOR ^b	358.5	35.9
Total remaining after July 1, 1988	831.5	1,659.9
Estimated cumulative Production before July 1, 1988 ^{a,b}	861.2	626.1
Ultimate Recovery^c	1,692.7	2,286.0

^aTotal gas production has been corrected to account for about 204.6 bcf of gas volume reinjected into producing pools.

^bCumulative production through December 1987 amounted to 850 MMSTB of oil and 1,200 bcf of natural gas. In the interim between the end of recorded production in December 1987 and the effective date of the Phase II Report, which is July 1, 1988, the contractor estimated cumulative production to have increased to 861.2 MMSTB of oil and 1,246.8 bcf of natural gas. The gas production, corrected for reinjection, is 626.1 bcf of natural gas.

^cPrevious published estimates of NPR-1 ultimate recovery were lower than these amounts. These estimates do not reflect ownership percentages of DOE and Chevron.

As reflected in table 2.2, over half (about 60 percent) of the oil and about 15 percent of the gas which the study estimated as being recoverable after July 1, 1988, fell into one of the categories in which there is some degree of uncertainty associated with the recovery. For example, 358.5 million barrels of oil are in the possible EOR category, which has the highest risk factor.

²A sixth reserve category was used by the contractor in phase III of the study to identify those reserves which fall into a potential reserve category. Potential reserves are reserves with an even greater degree of risk than the possible reserves. This category was not included in the gross reserve estimates and was only used to identify reserves that are in need of future studies to know their final disposition. These studies are discussed in chapter 3.

Economic Development and Production Plan for the Field

In the 1988 reserve study, the contractor also estimated the economic potential for the field by providing its view of the optimum economic plan for development and production. The plan was to reflect a timetable for development using various recovery techniques such as infill drilling, waterfloods, and EOR applications estimate costs of such development (both operating and investment), production rates, sales quantities, and revenues from the sales.³

To convert the estimates of gross reserves into an economic development and production plan for the field, the contractor had to perform a net present value analysis by evaluating various infill drilling, waterfloods, and EOR projects; apply the risk factors shown in table 2.3 to each reserve category to reflect the probability of success; and develop the total production/injection schedule and compare it with available field facility capacity.

Table 2.3: Reserve Categories and Probability of Success Factors Used to Calculate Remaining Recoverable Reserves^a

Figures in percent	
Reserve category	Probability of success
Proved developed	100.0
Proved undeveloped	87.5
Probable	67.5
Possible (excluding EOR)	37.5
Possible EOR	25.0

^aThe contractor selected the probability numbers based on ranges of probabilities developed by the Society of Petroleum Engineers.

As shown in table 2.4, the contractor's final economic development and production plan estimated that after July 1, 1988, about 445 million of the 831.5 million barrels of oil could be produced at a profit. The difference between gross and expected reserves reflects the contractor's determination that some projects had greater probabilities of economic failure than success. For example, for the 358.5 million barrels of oil in the possible EOR reserve category, the study applied a probability of success factor of 25 percent, resulting in recoverable reserves of about 89.6 million barrels of oil. After applying an economic analysis to those reserves, the study found only about 31.1 million barrels of oil that could be economically recovered. The contractor's estimate reflects the

³Infill drilling is the drilling of new wells between older producing wells. A waterflood is a secondary recovery method whereby water is injected into an oil and gas reservoir. EOR applications would include the process of injecting steam, gases, or chemicals into a reservoir.

Chapter 2
Reserve Report Estimates NPR-1's Oil and
Gas Reserves

uncertainty of EOR applications and the fact that they have not been applied or successfully demonstrated at NPR-1 to date.

Table 2.4: Estimated Oil and Gas Reserves Expected to Be Recovered After July 1, 1988

Reserve category	Expected reserves			
	Oil	Percent	Gas	Percent
MMSTB	Gas ^a	Gas ^a	Percent	
Proved developed	335.2	75.0	1,417.6	90.0
Proved undeveloped	22.2	5.0	61.9	4.0
Probable	30.9	7.0	84.4	5.0
Possible (excluding EOR)	25.2	6.0	10.4	1.0
Possible EOR	31.1	7.0	.8	
Total	444.6		1,575.1	

^aThe portion of natural gas to be extracted and sold from produced natural gas prior to gas reinjection is 204.6 billion cubic feet.

The development plan used net cash flow analysis to evaluate future expected DOE revenues less expenses and investments, one of the best methods used by government and industry to determine property values. The plan takes into account several development projects which the reserve study identified as economically attractive on a risked basis. The study identified the economic potential for the field through the combination of the risked economic evaluations for each reserve category and for the field as a whole.

As shown in table 2.5, four pricing and inflation scenarios were used to measure the economic potential of the field.

Table 2.5: Alternative Price and Inflation Factors and Economic Potential Modeling of NPR-1

Factors	Base	1	2	3
1988 oil price-Shallow Oil Zone ^a	\$16.63	\$14.81	\$14.81	\$14.81
1988 oil price-Stevens Oil Zone ^a	18.13	15.96	15.96	15.96
1988 natural gas liquids ^b	.30	.33	.33	.33
1988 natural gas ^c	2.24	2.10	2.10	2.10
1988 inflation rate	3.82	3.82	3.82	None
1993 inflation rate	2.00	2.30	3.00	None

^aOil price in dollars per barrel.

^bNatural gas liquids price in dollars per gallon.

^cNatural gas price in dollars per million British thermal units.

The economic potential of NPR-1 is shown in table 2.6. The base case assumes in 1988 that the price of oil was about \$16.63 per barrel in the

Shallow Oil Zone and \$18.13 per barrel in the Stevens Oil Zone; the price of natural gas was about \$2.24 per million British thermal units (Btu's); and the price of natural gas liquids was about \$0.30 per gallon. An inflation rate of 3.82 percent in nominal dollars was applied. The second case assumed a 1988 price of oil at \$14.81 per barrel in the Shallow Oil Zone and \$15.96 in the Stevens Oil Zone with natural gas at \$2.10 per million Btu's and natural gas liquids at about \$0.33 per gallon. The inflation rate began at 3.82 percent in 1988, but will drop to a constant 3 percent by 1992 and thereafter. Alternative cases varied the petroleum prices and the inflation rate. Estimated investment and operating costs were applied along with a 10-percent nominal discount rate to calculate the net present values shown.⁴

Table 2.6: The Study's Measurement of the Economic Potential of NPR-1

Dollars in millions

Reserve category	Base case	Alternate price case		
		1	2	3
Proved developed	\$4,807.0	\$3,892.7	\$3,900.0	\$3,190.5
Proved undeveloped	244.6	181.2	181.8	131.3
Probable	256.8	190.4	193.2	87.0
Possible (excluding EOR)	100.7	69.0	69.9	36.6
Possible EOR	26.2	(11.4)	(5.0)	0.0
Total	\$5,435.3	\$4,321.9	\$4,339.9	\$3,445.4
Total, less cost of new production facilities	\$5,261.5	\$4,148.1	\$4,166.0	\$3,307.6

The study maintains that these values should not be interpreted as a fair market value of the field but rather the contractor's best estimate of the reserves and their economic potential.

⁴The contractor used other discount rates to test the sensitivity of the economic potential of NPR-1.

Serious Questions Remain Regarding NPR-1's Revised Reserve Estimates and Data Supporting Them

DOE's revised reserve estimates for NPR-1 are still not accurate and up-to-date. Because of a 6-month contract time frame, the July 1988 reserve report was generally based on data from existing NPR-1 studies. The limitations of the data reduced the reliability of the reserve estimates. To improve the accuracy of these estimates, the contractor recommended additional geologic and engineering studies to clear up the uncertainties in the data used. These studies could substantially affect the reserve estimates and the value of the field.

Other work that is either ongoing or planned could also affect reserve estimates. These include (1) evaluations of all data concerning hydrocarbon resources found in DOE's recent deep well and (2) a determination of the potential impact of EOR methods on future oil production in the Shallow Oil Zone.

DOE has not decided whether to authorize the contractor to carry out the part of the contract relating to reevaluating the government's ownership share in NPR-1 that is planned under phase IV b.

Reserve Estimates Not Substantially Improved

A 6-month contract time frame was not long enough to permit the contractor to do technical analyses of the field and to support individual pool studies with well-by-well analyses. To complete the contract on time and meet DOE's statement of work objectives, the contractor used the best available data from other contract studies, which the contractor reviewed and spot-checked for accuracy.¹ The contractor qualified the final report with a statement that "it must be recognized that by their very nature reserve estimates are imprecise." Therefore, the soundness and validity of the revised reserve estimates provided were only as good as the data that supports them.

Factors Affecting the Estimates

In our view, two key factors affected the accuracy of the revised reserve estimates.

- Some of the pool/zone descriptions used in the study were not precise enough to calculate accurately the amount of original oil and gas in-place.
- Data concerning the movement of fluids between producing pools within the 31S Structure in the Stevens Oil Zone, although acknowledged by the

¹ A direct comparison of the 1988 contractor estimates to previous field estimates could not be done because earlier reserve estimates were developed using unlike methodologies, data, and approaches.

contractor, were not fully developed and reflected in the revised estimates of original oil and gas in-place.

Because of these two factors, two engineering methods used by the contractor to calculate original oil and gas in-place produced widely different estimates of original oil and gas in-place for many of the pools in the Stevens Oil Zone.

Quality of the Maps Supporting Pool/Zone Descriptions Need to Be Improved

To calculate the amounts of oil and gas in-place, accurate geologic maps of the pools and zones are needed.² To produce maps for the pools and zones, the contractor obtained geologic data from prior studies and analyzed production data from existing wells. However, rather than analyzing data from all wells at NPR-1 for this phase of the work, the contractor selected 130 wells from the total of about 2,300 wells drilled at NPR-1 for the detailed analysis. These wells, called "control wells," were distributed among the various pools and were to be computer-analyzed in detail from a geologic and engineering standpoint to validate or modify existing technical pool interpretations. The contractor's report pointed out that the field's reservoirs were generally studied but a well-by-well investigation was not done. Although DOE does use control wells for monitoring production pressures of the field, our review of 21 contractor-prepared reports to DOE between 1973 and 1988 for pool reserves, geology, and production operations showed that all but 3 of the 21 studied every well in the pool(s).

As was required by the statement of work, contractor-prepared maps were based on geologic data obtained in prior NPR-1 studies. While earlier studies have developed accurate geologic maps of some pools and zones, maps of other areas have not been updated and are not as detailed. Because of the short time which the contractor had to perform the reserve study, the contractor did not substantially revise the maps it used. Our review showed that the maps generally represented a validation of, or modification to, similar preexisting maps based on the contractor's review of the geologic data for selected key wells. Thus, some pools at the field continue to lack the quality and detail of the maps developed in other studies of the field.

In one instance, the contractor did not recognize that existing geologic maps of the 26R Pool it altered to conform to certain well data had been

²Mapping activities at NPR-1 depend primarily on the analysis of well logs and actual well production data. The mapping of producing fields is based on an interpretation of geology between wells. Local geologic conditions do not favor the use of some geophysical methods for mapping at NPR-1.

previously corrected to not use that data. The previous maps had been corrected to remove distortions because of the way the wells had been drilled in the pool. The contractor's remapping reintroduced the distortions.

The contractor recognized that better mapping of the field was needed. For example, the contractor selected 31 control wells for computer analyses of the Stevens Zone MBB/W31S, N/A shales, and C/D shales of the 31S Structure which have about 400 producing wells. The revised original oil in-place for these pools was estimated to be about 1.65 billion barrels. Knowing that its analyses were preliminary, the contractor recommended a comprehensive MBB/W31S well log analysis study in the Stevens Oil Zone as one of several additional studies of the field so that its calculation of original oil in-place could be improved. The contractor recommended that similar studies be carried out in other pools.

The Extent and Quantity of Fluid Movements Between Pools Not Known

To accurately estimate original oil and gas in-place at NPR-1, the extent of fluid migration between producing pools needs to be quantified. Although the July 1988 reserve report stated that the magnitude of fluid migrations in the 31S Structure alone could amount to over 10 million barrels of oil, and billions of cubic feet of gas, precise estimates of these fluid migration patterns could not be calculated. The migration is the result of past and current operating procedures of the owners, as well as the geology of the field. In a 1984 report, we stated that the production rate for oil and gas and methods for production had caused reservoir fluid and pressure imbalances in most producing structures at the field and could result in loss of ultimate recovery of oil.³ Following the release of our report, DOE stated at an October 1984 joint hearing of the Subcommittees of the House Armed Services Committee, the House Energy and Commerce Committee, and the House Interior and Insular Affairs Committee that it had begun a program of reevaluating the management and production practices of several pools at the field. Recent studies of the Stevens Zone's 31S Structure and 26R Pool (as well as a host of other consultants' reports dating back to 1977) have also recognized fluid migration as a significant problem at NPR-1.

Both DOE and Chevron recognize that fluid migration may occur. The unit operator completed a series of tests over the 1-year period ending June 30, 1989, and concluded that geologic communication between the 26R Pool and the N/A shales resulted in the movement of as much as

³Naval Petroleum Reserve No. 1—An Assessment of Production Alternatives, July 1984 (GAO/RCED-84-180, July 30, 1984).

15.5 million barrels of oil into the 26R Pool and 25 billion cubic feet of gas into the N/A shales. These tests also concluded that although geo-logic linkage is not suspected between the pools, wells completed in both the MBB/W31S sands and N/A shales pools in the same well bore have leaked significant amounts of gas (amount not calculated) into the N/A shales.⁴

**Engineering Calculations
Indicate Problems With Oil
In-Place Estimates**

Engineering analyses that were used to calculate original oil in-place in the Stevens Oil Zone reflected the problems caused by inadequate pool/zone descriptions and fluid movements between pools. Two engineering methods—volumetric and material balance—were used to calculate oil in-place for the major sand and shale pools in the Stevens Oil Zone.⁵ A general rule is that higher confidence is placed on the oil in-place estimates if the values produced by each method are relatively close and when sufficient data are available to perform equally sound calculations by both methods. However, as shown in table 3.1, the two engineering methods produced very different estimates of original oil in-place for many of the pools in the Stevens Oil Zone.

⁴This production method and associated problems were discussed in our report titled Naval Petroleum Reserve-1: Data Inaccuracies Complicate Production and Ownership Issues (GAO/RCED-87-105BR, Mar. 24, 1987).

⁵Material balance is a method of calculating original oil and gas in-place based on observing the effect of fluid production on pool pressure to estimate the volume of pool fluids.

The volumetric method calculates original oil and gas in-place on the basis of the area of the pool, the thickness of the productive rock, and the hydrocarbon storage capacity of the rock.

The volumetric method uses physical characteristics of oil-and gas-containing rocks, while the material balance method uses pool performance.

Table 3.1: Comparison of Original Oil In-Place Calculations Using Material Balance and Volumetric Methods for Stevens Zone Pools

Pool	Material balance	Volumetric	Value selected by contractor
MBB ^a (east)	380.0 ^c	378.0	378.0
MBB ^a (west)	^{c, d}	125.9	125.9
W31S ^b	^{c, d}	95.5	95.5
31S N/A shales	300.0 to 620.0	256.0	620.0
31S C/D shales	430.0	123.0	430.0
26R Sand	351.0	351.0	351.0
29R Shale	458.0	790.8	458.0
24Z/13Z sand	^d	121.8	121.8

^aMain Body B.

^bWestern 31 Sand.

^cThe contractor states that these calculations are intended to assist in understanding fluid movement within the MBB/W31S pools and are not representative of original oil in-place.

^dMaterial balance calculations for oil-in-place in these pools resulted in numbers lower than zero (a negative number).

For example, as shown in table 3.1, the contractor estimated original oil in-place for the N/A and C/D shales reservoirs, using the volumetric method, at 256 and 123 million barrels, respectively. However, using the material balance method, the estimate for the N/A shales was 620 million barrels, while the estimate for the C/D shales was 430 million barrels. The contractor selected the larger material balance values of 620 million and 430 million barrels of in-place oil for the N/A and C/D shales, respectively, because the volumetric estimates were based on inadequate mapping data and could not support current production levels when data for these pools are compared. The difference in estimates using the two methods, as well as the instances of positive and negative values from the material balance method, both contribute to the uncertainty in the contractor's shale pool estimates.

The contractor said, however, it believed their estimates of original oil and gas in-place were reasonable and consistent. They also said that fluid migration was taken into account in their calculations.

We believe that conflicting values may be resulting because the material balance method assumes that a pool has a defined closed system, whereby the limits of the pool are known and defined and fluid gains and losses within the pool are understood. For example, the MBB (West), W31S, and 24Z/13Z pools had negative values from the material balance calculations, which indicates a significant loss of energy that was not accounted for in the material balance calculation. As was previously

stated, fluid migration is occurring between pools in the Stevens Oil Zone and under the material balance calculations, the limits of these pools were not accurately known.

Contractor Recommends More Studies of Remaining Recoverable Reserves

To reduce the risk assigned in the revised reserve estimates, the contractor identified 33 additional studies that needed to be performed. These studies were to provide for new and improved geologic descriptions (18 studies) and for revised production practices (15 studies) for various pools in the field. Twenty-nine of the studies would be carried out in the 2 largest zones—the Stevens and Shallow Oil Zones. We found that many of the studies recommended had been recommended previously by other contractors to DOE.

Twenty-six of the studies are intended to reduce risk associated with much of the oil and gas reserves the contractor had placed in each of the reserve categories shown in table 2.2. We analyzed the contractor's estimates of risked reserves associated with these studies and grouped them by reserve category as shown in table 3.2. We found that 18 of the studies were associated with about 516.9 million barrels of oil and 326.1 billion cubic feet of gas, while the other 8 studies did not list oil and gas estimates.⁶

This represents about 62 percent of the oil and 20 percent of the gas estimated to be recovered after July 1, 1988.

Table 3.2: Estimated Oil and Gas Reserves Associated With Additional Studies at NPR-1

Reserve category	Number of studies	Expected reserves		Risked reserves ^a	
		Oil (MMSTB)	Gas (bcf)	Oil (MMSTB)	Gas (bcf)
Proved developed	3	21.2 ^b	69.3	21.2	69.3
Proved undeveloped	3	25.3	70.6	22.1	61.8
Probable	7	44.8	122.8	30.2	82.9
Possible	4	67.3	27.6	25.2	10.4
Possible EOR	4	358.3	35.8	89.6	8.9
Total		516.9	326.1	188.3	233.3

^aThe risked reserve values were obtained by multiplying the probability of success factors in table 2.3 by the reserves shown in this table.

^bAbout 21 million barrels of oil in the proved developed reserve category are included in the contractor's recommended studies because they are located in pools having other oil reserves classified in the lessor reserve categories.

⁶Three of the 18 recommended studies associated oil and gas estimates to more than 1 reserve category. Therefore, the number of studies listed in table 3.2 will total 21.

As a result of the studies, the estimated amount of oil and gas in the various categories could change (i.e., move to a higher or lower category). This would affect the estimated amount of oil and gas which is recoverable at NPR-1 and, as a result, the value of the reserve.

The remaining 7 studies recommended by the contractor that are not shown in table 3.2 relate to about 24.3 million barrels of risked oil and 17 billion cubic feet of risked gas that the contractor placed in a potential reserve category. Potential reserves are reserves with an even greater degree of risk than the possible reserves. For example, one of the seven studies would map and evaluate sands in the C/D shales interval to determine recovery potential of the pool. This study is important because DOE and Chevron have now recognized that other shale pools at the field must now be produced differently to produce at the maximum efficient rate. This study could increase the contractor's recoverable oil reserve estimates as a result of increasing the recovery factors for the sands contained within the C/D shales from 10 to 20 percent.

DOE Begins Work on the Additional Studies

In October 1988, DOE exercised the contract option to have Bergeson start phase IV work at NPR-1. We estimate, and DOE agrees, that on the basis of descriptions of work to be performed, the phase IV work will address parts of 11 of the 29 studies recommended by the contractor in his July 1988 report in the Shallow Oil and Stevens Oil Zones. Nine of the 11 studies will, in part, seek to improve geologic descriptions, while 2 will seek to address fluid migration problems in the Stevens Oil Zone. The work will take 12 months to complete and will include geologic descriptions and engineering analyses of both the Eastern Shallow Oil Zone and parts of the 31S Structure in the Stevens Oil Zone. Until the work is completed, how the work being carried out will affect the contractor's estimates of recoverable reserves is not certain. We did not technically verify the actual need for all the various studies recommended by the contractor. However, we found that at least 12 of the contractor's recommended studies had been recommended or were similar to recommendations in previous contractors' work for DOE.

The contractor estimated the cost to complete the 11 studies to be about \$2.15 million; however, DOE awarded the phase IV work at a cost of about \$1.09 million.⁷ To the extent that data concerning the purpose of the work being carried out were available, we compared it with the 11

⁷About \$800,000 of the phase IV work was budgeted for geologic and engineering analyses, while the remaining \$290,000 is for economic analyses and other project costs.

studies recommended in 1988. DOE attributes the difference in the cost estimates to the fact that some of the work proposed in these 11 studies is being performed in-house by the unit operator.

Most of the studies being carried out are intended to partially expand existing data bases and maps and comprehensive log analysis so that pool/zone descriptions can be improved. According to DOE, Bergeson's work provides additional information in areas of the field where no other contract work was being carried out and allows comparative evaluation of other studies.

- The work being carried out in the Shallow Oil Zone is estimated to cost about \$450,000. Six of the recommended studies that this work matches up to were estimated by the contractor in July 1988 to cost about \$1.34 million. Two of the recommended studies are only being partially performed. The most significant one is a study estimated to cost about \$869,400 that would evaluate the entire Eastern Shallow Oil Zone.
- The work being carried out in the Stevens Oil Zone is estimated to cost about \$350,000. Five of the recommended studies that this work matches up to were estimated by the contractor in July 1988 to cost about \$804,580. Three of five studies are for partially improving pool/zone descriptions for the N/A, B, and C/D shales pools by mapping and evaluating potentially productive sands in these pools.

According to the Director of the Naval Petroleum Reserves in California, the contractor's independent assessment of needed studies was done without prior knowledge of other studies which were completed, underway, or planned. The Director told us that DOE had completed, underway, or planned 30 of the 33 recommended studies using a variety of consulting firms. This includes the contractor's work under phase IV a.

While our scope of work did not include a review of all of DOE's geologic and engineering contract efforts carried out or underway at NPR-1, we believe that some of the 33 studies are still not covered by the ongoing and planned efforts. For example, the contractor recommended six studies for the Western Shallow Oil Zone. DOE stated that it funded no new work in the Western Shallow Oil Zone because of a recently completed study in that part of the zone. However, we found that the contractor (Bergeson) used this study in his work and, in fact, two of six recommendations were the same as those in the previous study. These two recommendations pertain to about 63.4 million barrels of oil and 13.6 billion cubic feet of gas in the probable and possible categories. Therefore, the reserve designations from the prior work will remain the same.

Until DOE completes its current round of contract work, it will not be possible to accurately assess what changes may occur in the reserve estimates for the field.

Additional Issues That Could Affect Reserve Estimates

In addition to the contract studies described above, DOE and Chevron are carrying out field tests of wells that could affect the reserve estimates. This work pertains to (1) tests to know the extent of potential petroleum resources in the deep zones below the existing unit and (2) EOR techniques such as steamflooding in the Shallow Oil Zone.

More Tests From Exploratory Drilling Needed

The July 1988 report briefly discusses available information on three NPR-1 deep test wells including Well 934-29R, an exploratory test well drilled to a depth of about 24,425 feet. Since data on prospective deep zones are still very limited, the contractor could not place much reliability on reserve estimates for these zones. The probability of success assigned by the contractor for 6 deep prospective areas did not exceed a 10-percent chance of success. A model to evaluate the reserves for these 6 areas estimated 21 billion cubic feet of possible recoverable gas reserves. Because of the degree of uncertainty associated with these reserves, they were not included in Bergeson's estimate of reserves.

While work concerning the July 1988 reserve report was in process, DOE released its unit operator's March 1988 report summarizing the results from drilling Well 934-29R. A 1987 drill stem test of the 17,400-foot to 17,500-foot interval resulted in a flow rate estimate of 791,000 cubic feet of gas per day, 1,568 barrels of water per day, and a small amount of gas condensate; natural gas was also found at a number of other intervals in the well. However, well tests conducted in 1989 were unsuccessful, according to DOE. According to DOE, the potential for finding additional oil, condensate, and gas below current productive zones at the field is still uncertain. A new understanding of the field's geology has occurred, and the potential for identifying new prospects in shallow and deep strata is now feasible.

Production testing of Well 934-29R is currently in process and additional exploratory drilling will be needed over the next few years to identify the potential of strata deeper than those now in production. Deep strata at this oil field are still virtually unexplored; however, DOE made a proposal to drill a new deep well in 1990. Whether or not deeper gas resources can be produced at a profit will depend on the future price of natural gas, the amount of gas (if any) present at various depths, and the cost of producing it.

**Enhanced Recovery Techniques
Are Possible in Shallow Oil Zone**

The July 1988 report shows that ultimate recovery in the Shallow Oil Zone could range from 500 million to 900 million barrels of oil since many wells in the zone are in the stripper category, and steamflooding or other EOR techniques may be applicable.⁸ The contractor's final report estimates that waterflooding the eastern part of the zone would add probable oil reserves of about 18.7 million barrels and possible oil reserves of about 58.4 million barrels.

Estimates prepared in previous studies of the zone confirm that uncertainty about the remaining reserves exists in the Shallow Oil Zone. A study projected in 1984 that about 380 million barrels of oil could be recovered by steamflooding the zone. DOE's long-range plan in 1987 projected a less optimistic steamflood and waterflood recovery of only about 15.2 million barrels. However, in 1988, the EOR subcontractor to Bergeson—Surtek—estimated that about 324 million barrels of possible reserves could be recovered with EOR methods other than steam. While most of these reserves were risked for net present value analysis, the potential does exist for adding a sizable amount of value to this older producing zone with the use of either secondary or tertiary recovery methods.

Experimental steamflooding is being tested in the zone. Earlier results from the wells in the pilot area test have shown nearly a doubling of well production rates over a several-month period. (See app. I.) The project is expected to go on until 1990, and at that time, steamflooding will be evaluated for possible future expansion into other areas of the zone. If the ultimate recovery of this zone is as high as some estimates previously mentioned, proved recoverable reserves at NPR-1 could nearly double.

**Data to Reevaluate the
Government's
Ownership Share Not
Obtained**

Option IV b of the reserve study would assist DOE in reevaluating the government's equity share in NPR-1. Our prior reports have pointed out that the administration's proposed sale of NPR-1 adds an extra dimension to the need for accurately defining the amount of oil that has been produced from the various pools within a single zone, the remaining recoverable reserves, and each owner's equity share. For example, our March 1987 report stated that the historical distribution of the oil produced from individual Stevens Zone pools was out of balance with the actual ownership of oil in those pools. This is because the oil is distributed on the basis of the overall zone ownership percentages established in the

⁸Stripper wells produce 10 or fewer barrels of oil per day for at least 1 year.

unit agreement.⁹ In a June 1988 report that discusses the same issue, we recommended that the Secretary of Energy authorize the Director, Office of Naval Petroleum Reserves and Oil Shales, to negotiate an agreement with the contractor to proceed with phase IV b of the current contract.¹⁰ DOE stated at that time that without further technical evaluation involving the additional geological and engineering studies being done as part of phase IV a, it did not want to begin work on phase IV b.

Imbalances will be corrected over the entire producing life of the field, thus allowing for a fair and equitable settlement of the owners' accounts when the field is depleted. However, if the government sells its share of NPR-1 in the immediate future, we previously reported that there currently is no fair and equitable way that settlement of any imbalance can be reached unless the current unit agreement and equities are modified. The phase IV option in the contract will allow DOE to develop data needed to reevaluate the government's equity share in NPR-1. DOE has agreed that negotiation between DOE and Chevron will be required on the unit plan contract prior to divestiture. Whether the equity ownership issue is made a part of contract negotiations or considered in a separate agreement, the reevaluation of equity planned in phase IV will provide useful data for DOE in determining each owner's ownership shares.

The amount of time required to complete negotiations with Chevron is highly uncertain. When DOE and Chevron negotiated the equity issue for some pools in the Stevens Zone in 1980, however, it took 2 years to reach an agreement. DOE and Chevron officials at NPR-1 advised us that they expect current negotiations for the Shallow Oil Zone to last the same amount of time.

⁹Oil produced from any pool usually is not in the same proportion as the total ownership of the zone. If one takes production from each pool to date, determines how much actually belongs to each owner on the basis of the pool ownership percentages, and adds the production for each owner for all the pools, the totals will probably not equal the total ownership percentage of the zone until the field is depleted.

¹⁰Naval Petroleum Reserve-1: Data Corrections Made but More Accurate Reserve Data Needed (GAO/RCED-88-174, June 28, 1988).

Economic Development and Production Plan Questionable for Current Operations

As we stated in our August 25, 1988, report, DOE needs improved data to make an accurate estimate of NPR-1's value to the government if it continues to hold and operate the field or to evaluate the acceptability of bids received from industry, should the field be sold. Although purposely not developed for the sale of the field, the contractor prepared an economic development and production plan in phase III of the study for the remaining recoverable reserves at NPR-1 after July 1, 1988, to establish the economic potential for the field. DOE told us that various assumptions would exist in an evaluation of an oil field and that any of them can and do change.

While the plan was useful for calculating an economic potential for the field, several assumptions in the plan make the remaining recoverable oil and gas estimates in table 2.4 questionable. First, the plan assumed that NPR-1 would substantially increase the number of wells and water injection in the Stevens MBB/W31S sands pools beginning in September 1988. This work has not happened and is still being studied. Second, the plan assumes that current ownership shares would exist into the future—the Shallow Oil Zone and Stevens Oil Zone equity ratios may change by 1990 or 1991, thus changing the dollar flows to DOE. Third, the size of EOR possible reserves in the Shallow Oil Zone are risked at a 25-percent probability of being produced, depending on (1) the results of steamflood or other EOR effort in the Shallow Oil Zone, (2) the size of the reserves, and (3) the reserves category, and the risking probability could change drastically by the time of a sale. Fourth, changes in operating strategies would also change production rates and timing for those Stevens pools affected by fluid migrations. Fifth, potential improvements in the reserve categories as a result of geologic and engineering studies currently being carried out could change the economic potential of the field. Lastly, perception of future oil prices may have a bigger effect than the rest of these factors combined.

Summary of GAO Observations on Data Inadequacies at NPR-1

The reserve study was completed in too short a time frame to come up with accurate and up-to-date reserve estimates for NPR-1. While the contractor made some progress in evaluating the recoverable reserves in the field, the contractor relied mainly on existing studies, indicated the risk and uncertainty associated with the reserve estimates, and recommended further studies. DOE said that 30 of the 33 recommended studies are either completed, underway, or planned as future contract studies. Until DOE completes this work, it will not be possible to accurately assess what changes may occur in the reserve estimates for the field. For example, according to DOE studies, there may be the opportunity to

Chapter 3
Serious Questions Remain Regarding NPR-1's
Revised Reserve Estimates and Data
Supporting Them

nearly double the estimated proved reserves at NPR-1 owing to the completion of pilot steamflood projects in the Shallow Oil Zone and testing of deep strata. We continue to believe, as we recommended in 1988, that a redetermination of the government's equity position will be needed in order to carry out a sale of NPR-1.

Summary of NPR-1's Geology and Major Contract Studies Since 1984

NPR-1 is located in the San Joaquin Valley of California and has produced oil and gas from formations ranging in age from the Miocene to Pleistocene. Production is obtained from sandstones draped over the two major anticlines of the eastern and western portions of the field, lens-shaped sandstones situated along the flanks of the anticlines, and areas of fractured shales or very fine-grained sandstones occurring mostly along the crest of the folds. Prior to July 1988, the ultimate recoverable reserves of the field were estimated to be about 1.5 billion barrels of oil and over 2 trillion cubic feet of natural gas. Included in the estimate are petroleum from five known zones—the Dry Gas Zone, the Shallow Oil Zone, the Stevens Oil Zone, the Carneros Zone, the Tulare Zone (currently unproductive), and the Asphalt Field.

The federal government and Chevron have conducted in-house and contract studies since 1942 concerning the various uncertainties about what oil and gas could be produced and at what rate as the field underwent changes over its production life. DOE formalized a program of reevaluating the management and production practices of each pool at the field starting in 1984.

NPR-1's Geology

Within these 5 zones at NPR-1 are 15 pools of varying sizes and 1 or more producing strata. Pools and strata are not all in separate and distinct areas, and some overlap at different depths. The pools and strata are listed in table I.1.

Appendix I
Summary of NPR-1's Geology and Major
Contract Studies Since 1984

**Table I.1: 15 Pools Located Within
NPR-1's 4 Zones**

Oil pool	Producing strata
Stevens Oil Zone	
24Z Sand	24Z Sand
2B	2B Sand A Shale 24Z & 29R
26R	26R Sand
MBB/W31S	MBB Sand W/31S Sand B-1, B-2, B-3 shales 31S Upper Western Sand
31S C/D	B-4, C Shale 31S D Shale 31S
31S N/A	N Shale 31S A Shale 31S
29R	B Shale 29R C Shale 29R D Shale 29R A Shale 24Z & 29R N Shale 24Z & 29R
24Z Shale	N Shale 24Z & 29R A Shale 24Z & 29R
NWS A1-A3	NW A-1 Sand NW A-2 Sand NW A-3 Sand
NWS A4-A6	NW A-4 Sand NW A-5 Sand NW A-6 Sand
NWS T/N	NW T-3 Sand NW T-4 Sand NW T-4A Sand NW T-5 Sand NW N-2 Shale NW T-5A Shale NW D Shale
Shallow Oil Zone^a	
Dry Gas Zone	
Carneros Zone	
Asphalto Field	
Tulare Zone	

^aProduction in this zone, the Dry Gas Zone, the Carneros Zone, the Asphalto Field, and the Tulare Zone are accounted for as a single pool within the zones.

**Major Contract Studies
of NPR-1's Geology**

As part of our request, we examined a few recently completed contract studies of major pools and zones at the field. Some of the most recent of these studies pertain to the Stevens Oil Zone (the 31S Structure and the 26R Pool) and to the Shallow Oil Zone (western sections). These studies had been reviewed by the contractor in the course of its work. Although

some of the principal objectives for the 31S Structure and 26R Pool studies have not yet been met, key reservoir management problems such as the allocation of production between commingled pools, fluid migration (oil, gas, and water) between pools, fluid contact (gas/oil and oil/water) trends, and productive sand intervals potential contained within the 31S shales have been identified.

31S Structure Study

The 31S Structure is a 7.5-mile-long by 1.5-mile-wide uplifted structure. The major producing sand pools which are contained within the 31S Structure are the 26R Sand, the MBB Sand, and the Western 31S (W31S) Sand. These pools contain the majority of the recoverable reserves from the Stevens Oil Zone.

A Task Force was created in May 1986 to review the 31S Structure, exclusive of the 26R Pool, which is also a part of the structure. The task force's objective was to provide the geologic and engineering data necessary to (1) optimize oil recovery from the B Shale/MBB/W31S sands intervals and (2) develop a plan to further exploit the N/A and C/D shales pools. The study was divided into two phases. Phase I, started in June 1986 and ended in April 1988, provides basic geologic and engineering data necessary for a more detailed evaluation of the structure; recommends remedial and deepening opportunities to maximize utilization of the existing wells; and identifies infill drilling opportunities. Phase II, which is in process, will build upon the data base generated during phase I and will involve a study of the primary and secondary recovery method performance of the 31S Structure so that a reservoir management plan to produce at MER can be recommended.

In phase I, the Task Force divided the structure into seven geographic areas and analyzed each area on a well-by-well basis. Individual well data for over 400 wells, such as well logs and well history files were reviewed. Geologic and engineering recommendations were also made for future well completions and drilling of wells. Phase I results have provided new geologic and engineering data bases and remedial and drilling opportunities for the structure. Beneficial results have been seen in petroleum production and gas/water injection increases that are occurring in the structure. According to the Task Force's final reports, increases to oil production amounted to over 9,000 barrels of oil per day in 1988. Another accomplishment is the development and revision of procedures to allocate production and injection to the Stevens Zone

pools, a problem we pointed out to DOE in prior reports.¹ In phase II, a computer simulation model is being developed.

A number of engineering problems associated with migration of oil, gas, and water between producing pools and strata in the 31S Structure were highlighted by the Task Force. This resulted in the need for methods to balance the movement and removal of oil, gas, and water over the entire structure. The unit operator observed the efforts from tests conducted over a 1-year period ending June 30, 1989, and confirmed that migration was still a significant problem in the structure. The MER was still projected by reservoir throughout the tests. In August 1989, the unit operator determined that the MBB/W31S Reservoir is not in geologic communication with other parts of the structure. Fluid migration is discussed in more detail in the remaining sections of this appendix and in chapter 3.

26R Pool Study

The 26R Pool is one of the largest at NPR-1 in terms of both ultimate and remaining recoverable oil. A pool study was started in January 1986 to prepare geologic and engineering data for detailed geologic descriptions. DOE intends to create a layered reservoir model suitable for predicting future reservoir performance and oil and gas reserves. This work is also being done in two phases. Phase I (completed in Jan. 1987) provided geologic descriptions, and phase II (which is in process) is intended to produce a computer simulation to predict the pool's future performance and recoverable reserves.

The geologic work in phase I found several defined units within the massive 26R Sand for which new maps and correlations were prepared. The technical analyses of new wells in the pool provided new data on the production mechanisms and on prior production problems in the pool. During the computer analysis and mapping segments of the study, sand thickness distortions were found and corrected. Our discussions with field personnel in Chevron and DOE found uniform approval and general acceptance of the geologic work, although the company which did the work was of the opinion that further geologic work was needed.

In phase II, two computer simulation models were developed but were determined to not properly model the reservoir. A third attempt, begun

¹Naval Petroleum Reserve-1: Data Inadequacies Complicate Production and Ownership Issues (GAO/RCED-87-105BR, Mar. 24, 1987) and Naval Petroleum Reserve-1: Data Corrections Made but More Accurate Reserve Data Needed (GAO/RCED-88-174, June 28, 1988).

in 1988, is in progress. The models did produce data disclosing that oil may be isolated in the upper part of the reservoir, but should eventually be recovered by long-term gravity drainage. They also showed that fluid migration is occurring in and out of the pool through commingled wells and natural geologic contact with the adjacent and overlying shales. In addition, they disclosed that ultimate recovery was estimated to be (under the best-modeling-case scenario) 203.1 million barrels of oil, or 58.7 percent of original oil in place (calculated to be about 346 million barrels of oil).

The ongoing modeling efforts will utilize two different approaches, and according to DOE, are scheduled for completion in February 1990.

Shallow Oil Zone Studies

The Shallow Oil Zone, the oldest producing zone at NPR-1, has various sands that are mostly commingled and are very discontinuous. These sands are also broken by a large number of geologic faults. Because of the long history of production, blowouts, and poor production techniques, the zone is produced by a significant number of stripper wells. Steamflooding is being tested because DOE and other contractors have stated that oil remains bypassed or not produced because of low reservoir pressure. For example, oil production from test wells in the pilot area increased from a per-well average of 45 barrels per day to 89 barrels per day as a result of repressurization of the sands being injected with steam. Experimental steamflooding began in 1987 and is expected to go on until 1990, when the project will be evaluated for possible future expansion into other zone areas.

DOE's latest contract study for the zone, completed in 1987, covered western sections of the zone. It included detailed well-by-well geologic, engineering, and economic analyses of various sands. That study also produced data which may be used as input in a potential future equity determination. The equity parts of that study are discussed in chapter 3.

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